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Investigation of the Prediction of Lightning Strikes
Using Neural Networks

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INVESTIGATION OF THE PREDICTION OF LIGHTNING STRIKES USING NEURAL NETWORKS

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Abstract

A neural network is being trained to predict lightning at Cape Canaveral for periods up to two hours in advance. Inputs consists of ground based field mill data, meteorological tower data, lightning location data and radiosonde data. High values of the field mill data and rapid changes in the field mill data, offset in time, provide the "forecasts" or "desired output values" used to train the neural network through backpropagation. Examples of input data are shown and an example of data compression using a hidden layer in the neural network is discussed.

1. Introduction

Because of the destruction by lightning of Atlas-Centaur 67 and its communication satellite payload on 27 March 1987 (1), new launch commit criteria with respect to lightning were imposed by NASA and the Air Force for missile launches from the national ranges. These criteria are very conservative and restrict the available launch windows especially during summer months at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS) in Florida. The Air Force's Air Weather Service (AWS) provides weather support, including the forecasting of lightning, to both NASA and Department of Defense (DoD) at Cape Canaveral AFS and at Kennedy Space Center. In an effort to improve the forecasting of lightning, work has been undertaken to apply neural networks to the prediction of lightning. Specifically, it is intended to construct and train a neural network architecture to generate spatial maps of predicted probabilities of lightning over the CCAFS/KSC complex. A pilot program is currently underway which is utilizing data from the ground based electric field mills, from the cloud-to-ground lightning mapping network, and from the meteorological network currently operating at CCAFS/KSC. The neural network program developed by James Bay, Inc. and licensed to KTAADN, Inc. operates on a Macintosh IIx and employs backpropagation for training.

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2. Background

Of all the categories of weather which cause damage to Air Force aircraft, lightning accounts for roughly half at an estimated loss of \$10M per year. Lightning is a particular problem at CCAFS/KSC because of the high number of thunderstorms over central Florida (see Figure 1). Disasters such as the loss of Atlas-Centaur 67 (1) and the strikes to Apollo 12 (2) emphasize the vulnerability of the launch operations to lightning. In addition, the fueling of rockets, the handling of explosives and operations on the tall, exposed structures require timely lightning forecasts in excess of one hour. Air Weather Service forecasters supporting these operations use the standard meteorological inputs but also utilize other information unique to CCAFS/KSC such as a thirty one station electric field mill network shown in Figure 2, a meso-meteorological surface network, a multi-level meteorological tower network (Figure 3), and the Lightning Location and Protection (LLP) system (3).

The problem being addressed by this effort is to make better use of the wealth of data coming into the Air Weather Service forecast center so that the duty forecasters can make more accurate predictions of both the natural, cloud-to-ground lightning and the triggered lightning (4) which is initiated by a vehicle (rocket or aircraft) as the vehicle passes through or near electrically charged clouds.

3. Approach

The first phase of this effort is simply a pilot program which, by design, is limited in extent. In particular, lightning within the following few hours will be predicted, and the inputs will consist of just the ground based field mill data, standard local radiosonde data, mesonet data and tower data. These data are readily available and are used extensively by the forecasters in real-time. We also feel that the success of the work by Watson et al (5 and 6) using convergence calculations made from limited tower data in predicting the

formation of cumulus clouds and subsequent lightning can be improved upon by using all of the data from all levels of the towers as inputs to the neural network.

We are well aware of the fact that there are other sources of data which the Air Weather Service forecasters use extensively in their prediction of lightning. In particular, weather radar data from the NOAA radar at Daytona Beach, Florida and the fine detail data from the weather radar at Patrick AFB, Florida are considered extremely important by the forecasters in the prediction of lightning. The forecasters strongly recommended that the radar data be included as part of our pilot study, but we found that the collection, conversion and utilization of the radar data by the neural network system was well beyond the scope of the resources available for the pilot program.

Next in importance according to the forecasters were the data provided by the lightning detection networks. The one of primary use is the KSC LLP system (3) which provides locations of cloud-to-ground strikes over central Florida. These data are being used as inputs to the neural network.

Satellite weather pictures, both the visible and the infrared, are used to some extent for lightning prediction, but generally for longer term predictions; i.e., tracking fronts during the winter time and watching for convective development in unstable air masses. Usually the pictures are available only every half hour which is a long time when compared to the average 20 to 40 minute lifetime of a typical convective cell. Future satellites will provide more frequent pictures, better resolution of detail, lightning mapper capability and improved details of the water vapor distribution in the atmosphere. Inclusion of satellite data is beyond the scope of this pilot program.

4. Neural Network Details

Backpropagation is being used to train the network. As mentioned above, inputs are from the ground based electric field mill network, from the meso-meteorological network, from the towers, from the LLP system, and from the local radiosonde runs. The choice of the "target" which the network must learn is important. Since triggered lightning is as important to the Air Force and NASA missions as cloud-to-ground strokes, we sought training data related to such conditions. We selected either high electric field mill data or rapid changes in electric field mill data as training data. These we take to be indicative of electrified clouds in the vicinity. The target data were used offset in time from the inputs so as to be predictive. An advantage of training the network to

predict high or rapidly changing electric field is that cloud electrification is often better correlated with other meteorological data than are actual cloud-to-ground strokes.

Several network architectures appear to be promising candidates for this work, but only one could be attempted with the resources available in this pilot study. This is illustrated in Figure 4. Using this network, the usefulness of wind, electric field mill, radiosonde and convergence data will be assessed by using various combinations as inputs.

5. Preliminary Results

The field mill data show wide variations in the electric fields at the ground as thunderstorms pass over head and when there are nearby lightning strikes. Figure 5 shows the variations at two of the field mills on 18 July 1988. Note the electrical activity starting around 1130 GMT, with a maximum of 5500 V/m around 1350 GMT.

An example of Total Area Divergence as calculated using the methods of Watson et al (5 and 6) is shown in Figure 6. Since we know that these values contain some predictive information, they are calculated from the raw meteorological data and are used as an independent input into the neural network. If they were not used as independent input values we are confident that they would be "found" by the neural network during training.

Figure 7 displays the cloud-to-ground strikes occurring in the area. There were many more strikes reported by the LLP system, but only those in the area covered are shown. Notice the Shuttle Landing Strip on the northern part of Merritt Island and the Tyco Airport on the mainland. All the KSC LLP cloud-to-ground lightning strikes detected in the vicinity on 24 July 1988 are shown.

We began working with the field mill data to reduce the number of elements in the hidden layers of the network shown in Figure 4. Using just the field mill data alone to predict itself (we let the output layer equal the input layer in a simple three layer network), the number of elements in the single hidden layer was reduced from 20 to 15 to 10 to 8 and then to 6. It was found (7) that the error increased sharply when the number of elements in the hidden layer was less than 8. This suggests that 8 or 10 elements may be used in this first hidden layer to adequately pass the information contained in the 31 field mills up through the network. This is in line with some findings in the field of neural networks which have shown that the minimum number of elements in such an auto-associative network must be larger than $\lceil \log_2 N \rceil$ where N is the number of input/output elements. In our case $N=31$, so the

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minimum number of elements in the hidden layer must exceed 5.

As mentioned above, the neural network is being implemented on a Macintosh IIx. Figure 8 is an example of the screen display showing some of the windows which will be available to the operator/forecaster. The top left gives the lightning probability status as computed by the neural network, and just below is the sensor status where the operator can remove inputs to the neural network. One of the features of neural networks is that the output degrades gracefully as inputs are removed one by one. The map of the KSC/CCAFS area in the top right shows the major causeways, the land areas in white, the Shuttle Landing Strip, the Tyco Airport, the field mills and the meteorological towers. On the color display the field mills and the towers are different colors. The solid dot near the top of Merritt Island is the particular tower which is shaded in the lower left window. The lower right window is a diagram of the neural network where the weights connecting the elements are color coded. Other windows will provide the operator/forecaster instructions for operating the system and displaying data.

Acknowledgments

The authors wish to thank Mr. Ilya Schiller for creating the user interface of the neural network predictor system, Mr. Brian Burke for deciphering and abstracting data from the Cyber tapes and exploring the auto-associative network, Dr. Ronald Holle, Dr. James Stark Draper and Mr. Ralph Markson for useful discussions, Dr. Irving Watson for providing the wind divergence calculations, Mr. Hal Herring and colleagues at CSR/Weather for providing Cyber tapes with electric field mill, wind, LLP and radiosonde data.

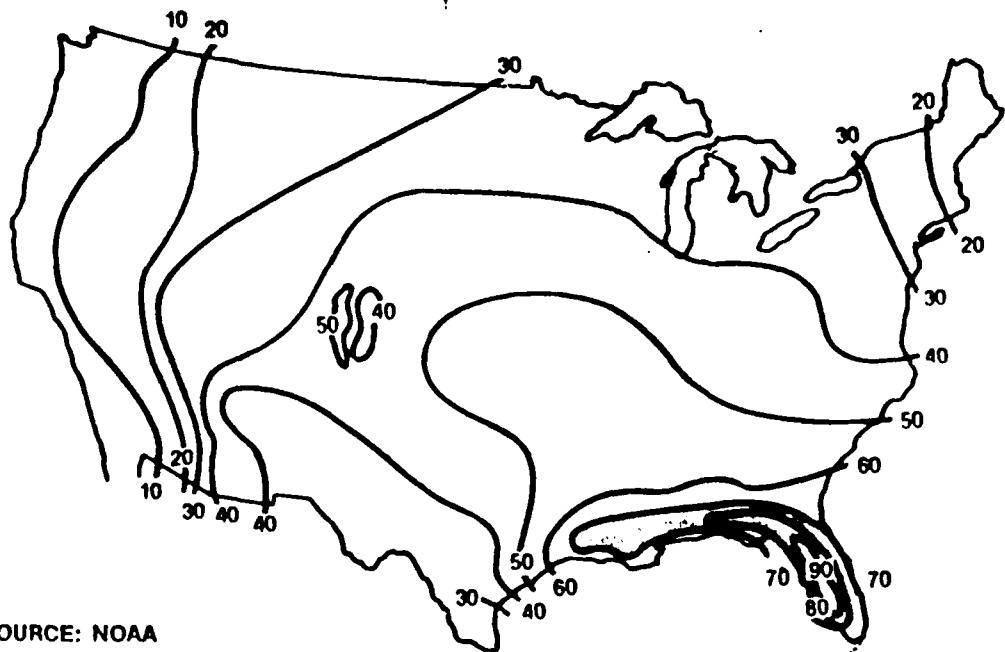
Acronyms

AFS	= Air Force Station
AWS	= Air Weather Service
CCAFS	= Cape Canaveral Air Force Station
DoD	= Department of Defense
KSC	= Kennedy Space Center
LLP	= Lightning Location and Protection system
NOAA	= National Oceanic and Atmospheric Administration

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AVERAGE NUMBER OF THUNDERSTORM DAYS IN THE UNITED STATES



SOURCE: NOAA

Figure 1. Thunderstorm Frequency over the United States

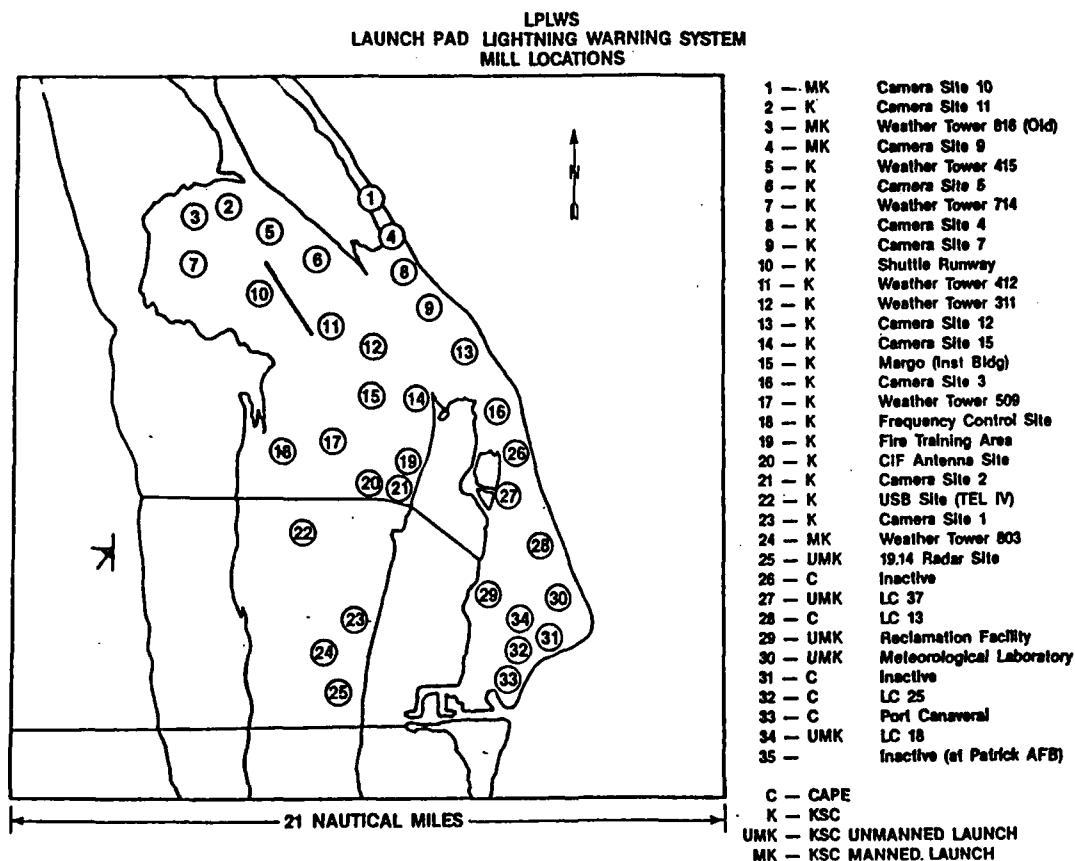


Figure 2. Ground Based Electric Field Mill Network over KSC/CCAFS

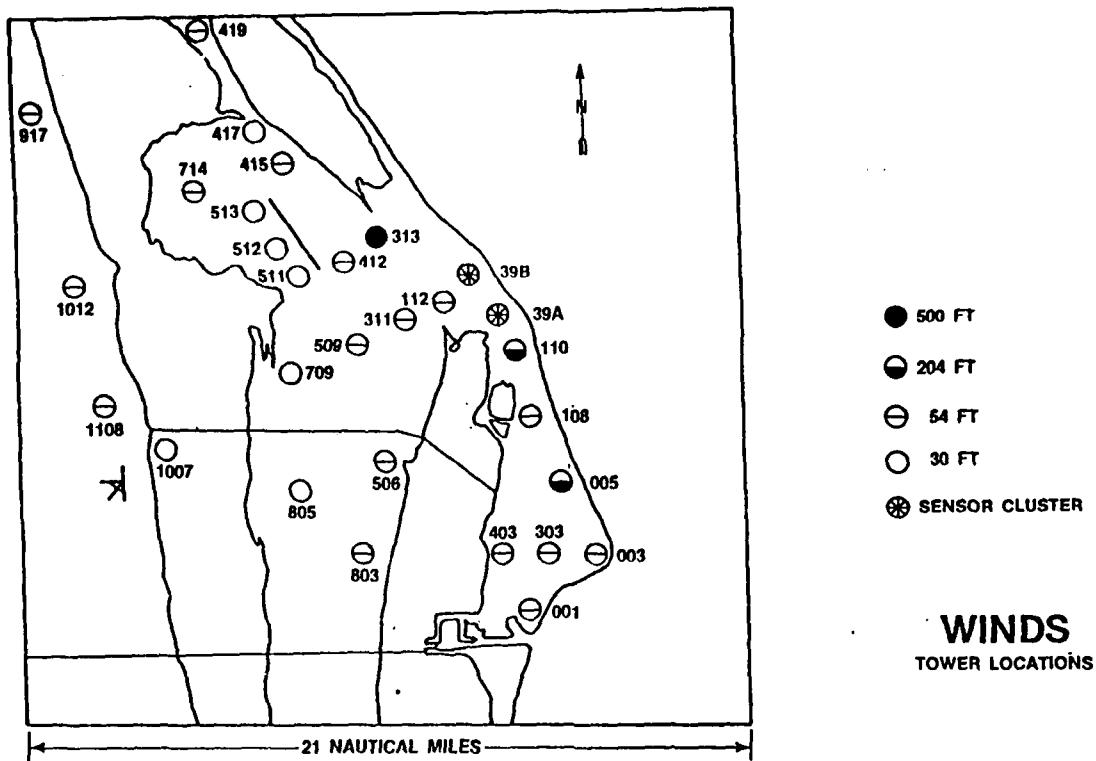
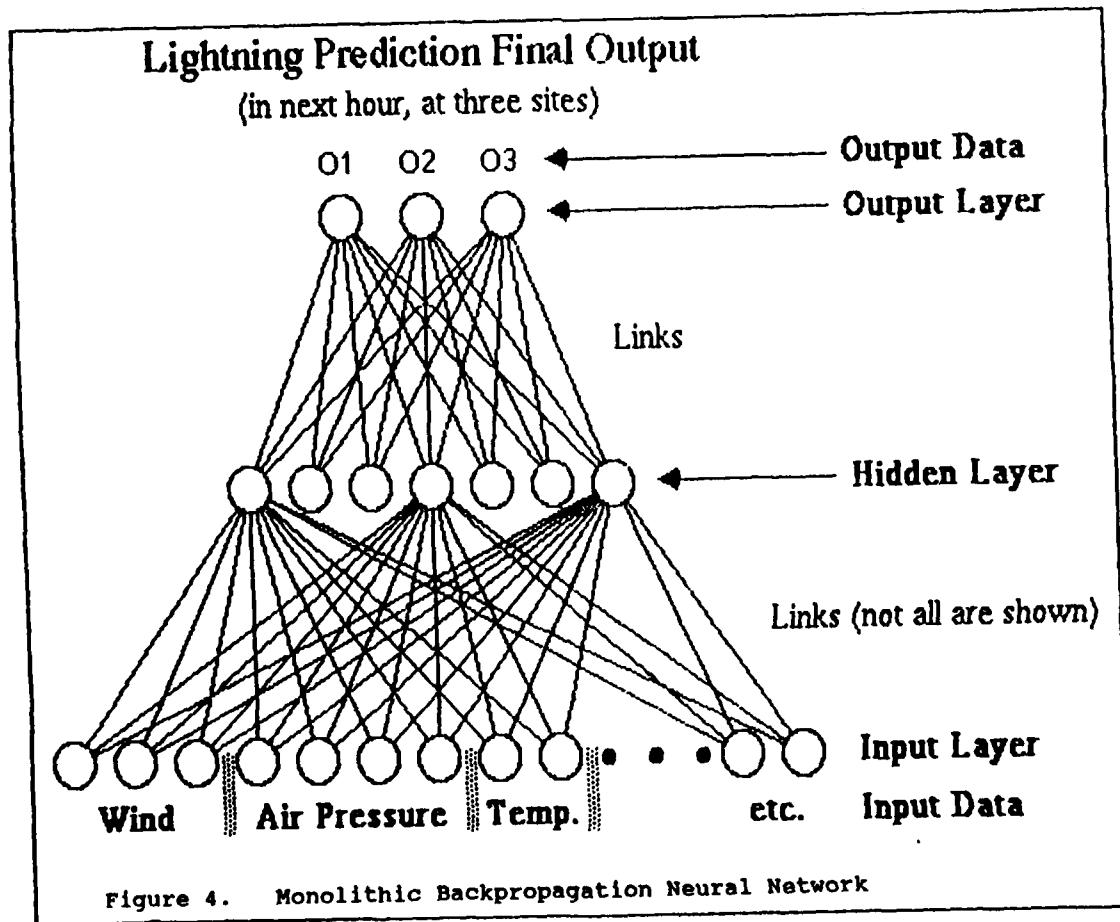


Figure 3. Meteorological Tower Network over and Around KSC/CCAFS



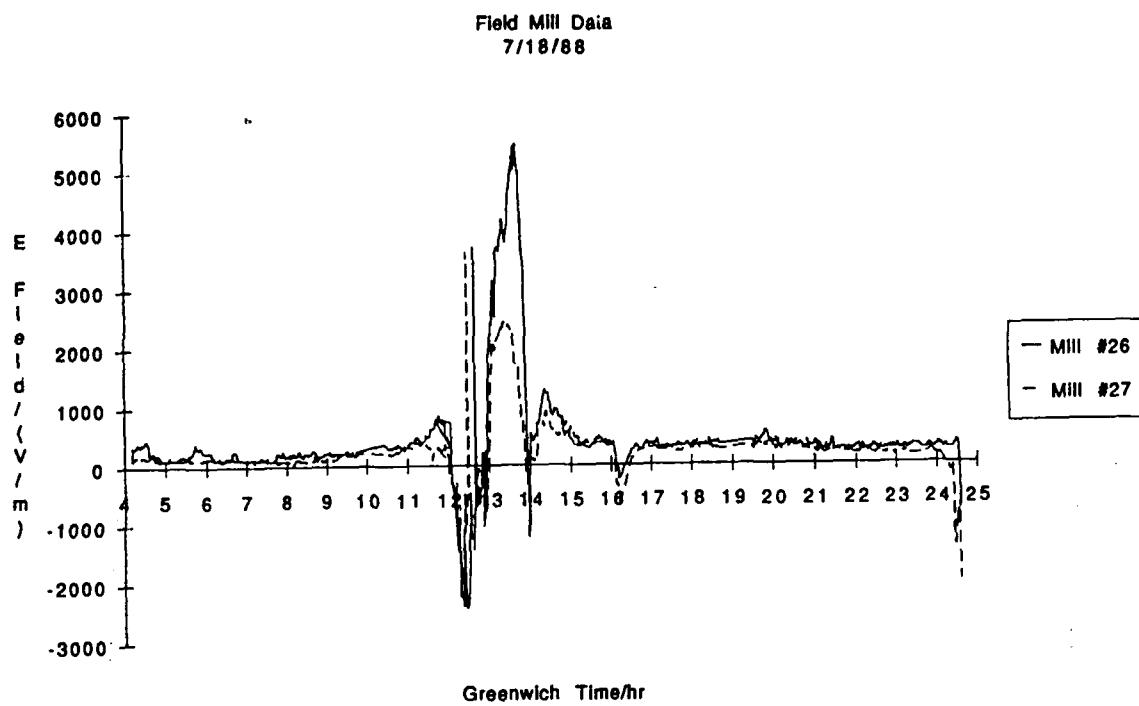


Figure 5. Electric Field Mill Data for Mills #26 and #27 on 18 July 1988

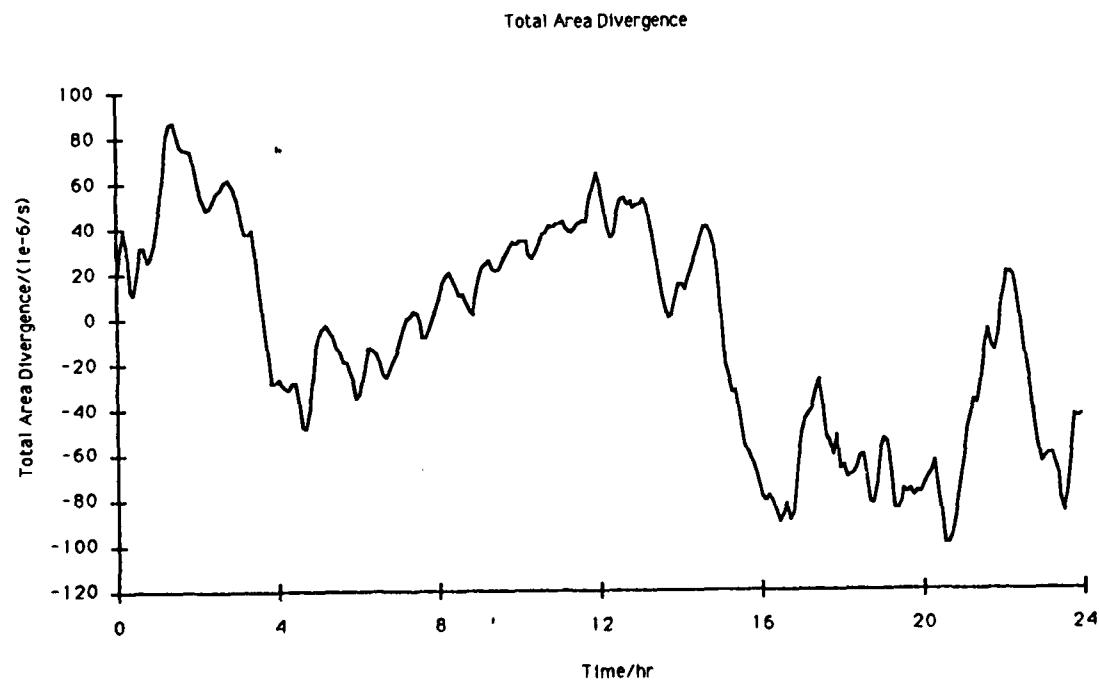


Figure 6. Example of Total Area Divergence over KSC/CCAFS on 18 Sept 1989

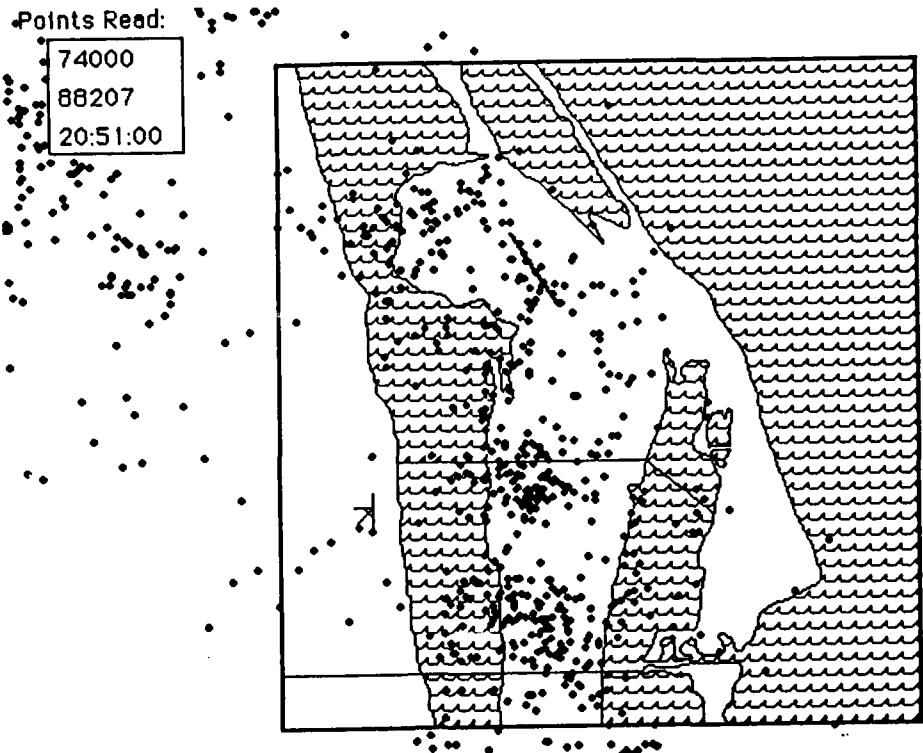


Figure 7. KSC LLP Cloud-to-Ground Lightning Strikes for 24 July 1988

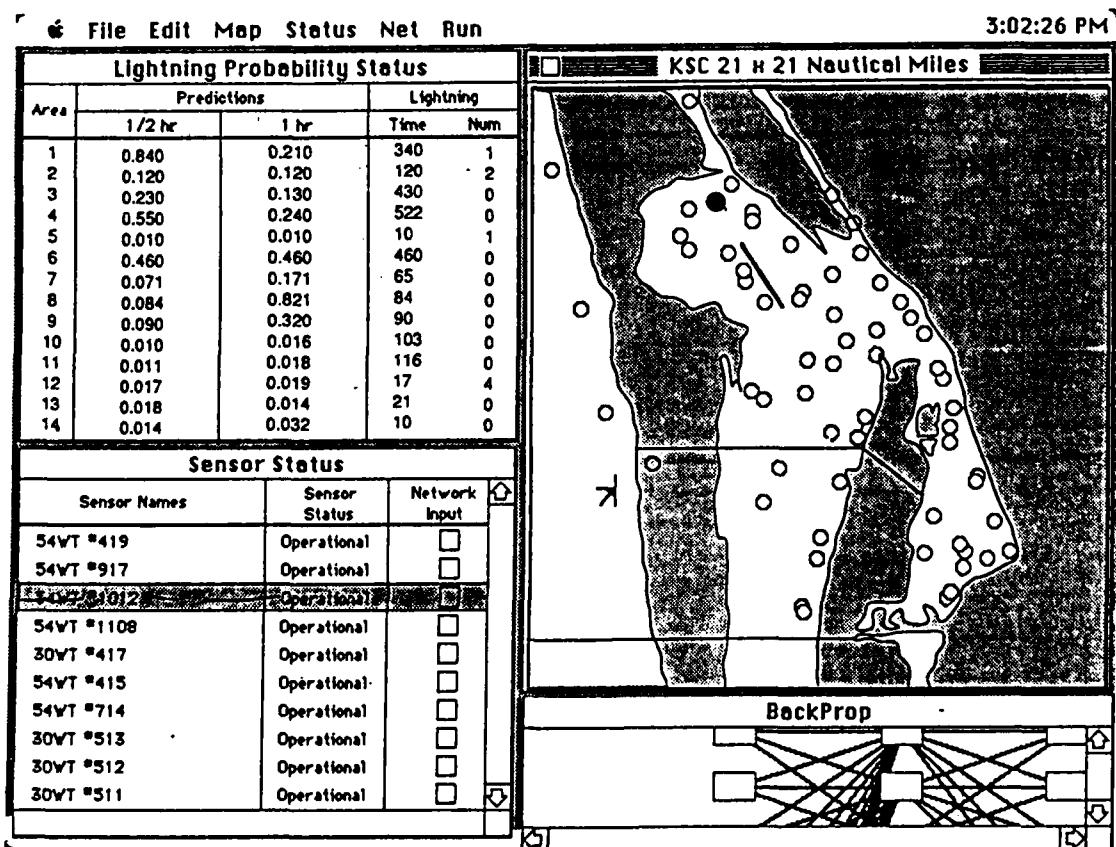


Figure 8. Some of the Neural Network Windows Available to the Operator or Forecaster on the Macintosh IIx